

NUMERICAL ANALYSIS OF ELEVATED FRAMED STAGING SHALLOW TANK BY NEWMARK'S STEP-BY-STEP METHOD

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ABSTRACT

Water tank is a life line structure, are extensively used in water supply facilities, oil, gas and nuclear power plants, for storage of variety of liquid material, e.g. Oil, LNG. Due to earthquake critical damage to elevated R. C. C. tanks are found. In the present work, a 50 m³ water tank has been analyzed for x-direction earthquake ground motion for fixed and an isolation system (Elastomeric bearing) is used to reduce the behavior of the basic response e.g. base shear, time period, tower drift, flexibility, of the elevated R. C. C. tanks. For solving complicated equation of motion for a coupled analysis a Newmark's step by step iteration method is used. After detailed analysis of 50 kL water tank, due to isolation base shear reduced significantly and the sloshing displacement increases as compared to non-isolated tank, also increase in isolation period from 2 sec to 4 sec, base shear reduced significantly.

Keywords: base shear, Elastomeric bearing, flexibility, R.C.C.tanks, time period, tower drift

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1. INTRODUCTION

One of the most important lifeline structure used for storing liquefied material is R.C.C.water tank which is commonly used as storing various liquid material e.g. water, oil, LPG and hazardous chemicals. It is reported from last some years that tanks are suffered through heaviest damages due to earthquake, some of the mentioned reports are Bhuj in 2001, Jabalpur in 1997, Latur in 1993, Nigata in 1964, Alaska in 1964, Park Field in 1966, Imperial Country in 1979, Colinga in 1983, Northridge in 1994 and Kocaeli 1999. Due to this fact in recent years, research on base isolation techniques has made significant progress in the reduction of seismic response of liquid storage tanks. Some studies for modelling ground liquid storage tanks and their dynamic response have been performed to acknowledge their reaction [1].

Actually, Housner [2] did his work on water tank and developed a mathematical model in which the water mass of the liquid portion that accelerates with the tank is called as "impulsive" and the mass near the surface of the tank which exhibits the sloshing movements

is called as convective mass. Haroun [3, 4] modified the Housner's [2] by considering the flexibility of tank wall in the seismic analysis. Chen and Kianoush [5] work on generalised SDOF system for seismic analysis of concrete rectangular liquid storage tanks and compare the results with FEM model, which are more accurate. This study also recommended that the effect of the flexibility of a tank wall should be considered in the calculation of hydrodynamic pressures for concrete rectangular tanks. Kianoush and Ghaemmaghami [6] investigated the behaviour of rectangular concrete water tank by FEM model. Chalhoub and Kelly [7, 8] conclude that the sloshing mass in the tank increases slightly with the decrease of total hydrodynamics pressure due to isolation. Kim and Lee [9] experimentally investigated the response of unidirectional excitation of base isolated water tank water tank and it is found that base isolation is very effective in reducing the response of tank, same results has been narrates by Liang and Tang [10]. Malhotra [11, 12] use different isolation system for reducing the various responses of the tank and suggested that base isolation system is better than the conventional techniques. Shrimali and Jangid [13, 14] performed the experiment by considering the interaction effect of the bearing forces with imparting the off-diagonal component in the analysis and it is observed that the seismic response of isolated tank is insensitive to interaction effect of the bearing forces.

2. MATHEMATICAL MODELLING OF WATER TANK

2.1. Governing Equation in Liquid Domain

In this work, following assumption are made,

- i) Fluid is ideal
- ii) Fluid is in viscid and incompressible
- iii) Fluid follow irrotational flow.

Following momentum equation is used for defining the flow.

$$\mathbf{u} = \frac{\partial \phi}{\partial x} \quad \mathbf{v} = \frac{\partial \phi}{\partial y} \quad \mathbf{w} = \frac{\partial \phi}{\partial z} \quad (1.1)$$

Where, ϕ – **velocity potential** x, y, z –position vector which is given by

The governing equation of liquid motion is replaced by the Laplace equation.

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad \text{or} \quad \nabla^2 \phi = 0 \quad (1.2)$$

Dynamic boundary condition of the free surface can be represented in general format by following equation which also defines surface sloshing and pressure is assumed to be zero at the water surface with some approximation.

Boundary condition of the fluid-structure interface formula is given by equation 4, [15],

$$\frac{\partial \phi}{\partial n} = vn(t) \quad (1.3)$$

Where 'g' is the acceleration due to gravity and $vn(t)$ is the relative normal fluid velocity at the tank wall at time (t).

2.2. Formulation of Liquid mass in water tank

Fig. 1 shows the idealized structural model of elevated R.C.C. liquid storage tank mounted on Laminated Rubber Bearing (with and without Lead). The Elastomeric bearings are placed between the base and foundation of the tank for isolation. The contained continuous liquid mass is modelled as two degrees of freedom and liquid is lumped as convective, and impulsive masses are modelled as m_c, m_i respectively. The convective and impulsive masses are modelled as spring having stiffness k_c , and k_i as shown in fig.1, with damping constants c_c and c_i , respectively [25].

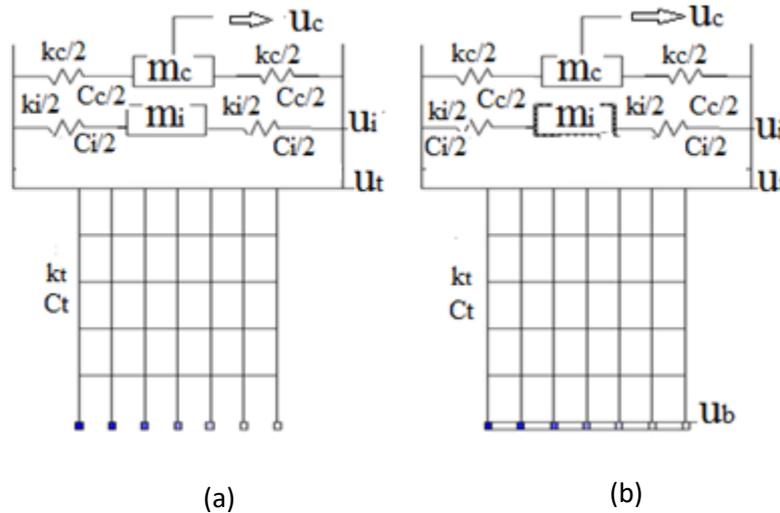


Figure.1. Structural model of elevated liquid storage R.C.C. tank: (a) non-isolated, (b) With isolation at Bottom of column (isolated model-I) [26].

2.2.1. Shallow and Slender Tanks [23, 24]

For a cylindrical storage tank of radius R, containing an incompressible liquid of mass density (ρ_w) of the liquid. Filled to a depth H, the total mass of liquid is given by.

$$m = \pi R^2 H \rho_w \tag{1.4}$$

Shallow tank

A shallow tank is one with height to the radius ratio of less or equal to 1.5. The lumped mass model for this case is as shown in Fig. 2 It consists of a mass, m_i , moving with the rigid tank wall producing the impulsive force and a mass m_c , producing the convective force.

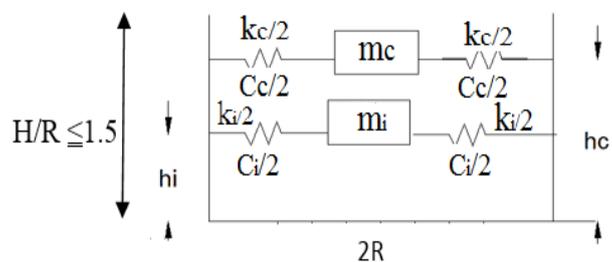


Figure 2 Shallow Tank- Lumped mass approach for $H/R \leq 1.5$ using Housner's method [26]

The heights of these masses were located on the basis of producing the correct moment about the base. These heights are designated by the letters h_i and h_c as shown in Fig. 2. The heights h_i and h_c are used to calculate the bending moments about the base of the structure. The bending moment just above the base is resisted by the shell.

$$h_i = \frac{3}{8} H \tag{1.5}$$

$$h_c = H \left[1 - \frac{\cosh\left(\frac{1.84H}{R}\right) - 1}{1.84 \left(\frac{H}{R}\right) \cdot \sinh\left(1.84 \left(\frac{H}{R}\right)\right)} \right] \tag{1.6}$$

$$\frac{m_i}{m} = \frac{\tanh\left(0.866 \frac{D}{h}\right)}{0.866 \frac{D}{h}} \tag{1.7}$$

$$\frac{m_c}{m} = 0.23 \frac{\tanh\left(3.68 \frac{h}{D}\right)}{\frac{h}{D}} \quad (1.8)$$

2.3. Force deformation behavior of isolation system (with and without Lead LRB).

2.3.1. Laminated Rubber Bearings

The main components of laminated rubber bearings (LRB) are steel and rubber plates built in the alternate layers [28]. The restoring force developed in the bearing, F_b is given by

$$F_b = c_b \dot{x}_b + k_b x_b \quad (1.9)$$

Where c_b and k_b are damping and stiffness of LRB system, respectively.

$$k_b = \left(\frac{2\pi}{T_b}\right)^2 (M + m_{\text{staging}} + m_b) \quad (2)$$

$$c_b = 2\xi_b \omega_b (M + m_{\text{staging}} + m_b) \quad (2.1)$$

And $\omega_b = \left(\frac{2\pi}{T_b}\right)$ is the isolation frequency.

2.3.2. Lead-Rubber Bearings

Lead rubber bearing are also called as N-Z bearings, same appearance as laminated rubber bearing containing a centrally a lead core used for energy dissipation and useful in a minor earthquake [29, 30]. For the present study, Wen's model [31] is used to characterize the hysteretic behavior of the N-Z bearings. The restoring force developed in the isolation bearing is given by.

$$F_b = c_b \dot{x}_b + \alpha k_b x_b + (1 - \alpha) F_y Z \quad (2.2)$$

Where F_y is the yield strength of the bearing; α is an index which represent the ratio of post to pre-yielding stiffness; k_b is the initial stiffness of the bearing; c_b is the viscous damping of the bearing; and Z is the non-dimensional hysteretic displacement component satisfying the following non-linear first order differential equation expressed as

$$\frac{q}{dt} \frac{dZ}{dt} = -\beta |\dot{x}_b| |Z| |Z|^{n-1} - \tau \dot{x}_b |Z|^n + A \dot{x}_b \quad (2.3)$$

Where q is the yield displacement; dimensionless parameters β , τ , A and n are selected such that predicted response from the model closely matches with the experimental results. The parameter n is an integer constant, which controls smoothness of transition from elastic to the plastic response. The N-Z system is characterized by the isolation period (T_b), damping ratio (ξ_b) and normalized yield strength, i.e. F_y/W (where $W = Mg$ is the total weight of the building; and g is the acceleration due to gravity). The other parameters of the N-Z system are held constant with $q = 2.5$ cm, $\beta = \tau = 0.5$, $A = 1$ and $n = 2$.

2.4. Newmark's step-by-step method of the model [32]

Since the damping level in the isolator, supporting tower and vibrating liquid is very different, the equations of motion of the isolated elevated liquid storage tank cannot be solved using classical modal superposition technique. Alternatively, the equations of motion are solved in the incremental form using Newmark's step-by-step method assuming linear variation of acceleration over the small-time interval, Δt . The equations of motion in the incremental form are written as.

$$[m]\{\ddot{x}\} + [c]\{\dot{x}\} + [k]\{x\} + \Delta F = -[m]\{r\}\ddot{u}_g \quad (2.4)$$

And expressed as below for Shallow Tank,

$$\begin{bmatrix} m_c & m_c & m_c \\ m_c & M + m_b & M + m_b \\ m_c & M + m_b & M + 3m_b \end{bmatrix} \begin{Bmatrix} \ddot{x}_c \\ \ddot{x}_t \\ \ddot{x}_b \end{Bmatrix} + \begin{bmatrix} C_c & 0 & 0 \\ 0 & C_t & 0 \\ 0 & 0 & C_b \end{bmatrix} \begin{Bmatrix} \dot{x}_c \\ \dot{x}_t \\ \dot{x}_b \end{Bmatrix} + \begin{bmatrix} k_c & 0 & 0 \\ 0 & k_t & 0 \\ 0 & 0 & k_b \end{bmatrix} \begin{Bmatrix} x_c \\ x_t \\ x_b \end{Bmatrix} + \Delta F \\ = - \begin{bmatrix} m_c & m_c & m_c \\ m_c & m_c & M + m_b \\ m_c & M + m_b & M + 3m_b \end{bmatrix} \begin{Bmatrix} 0 \\ 0 \\ 1 \end{Bmatrix} \ddot{u}_g \quad (2.5)$$

The displacement vector for the isolated model is expressed as $\{x\} = \{x_c, x_i, x_t, x_b\}^T$, $x_c = u_c - u_t$, is the relative displacement of the sloshing mass, $x_i = u_i - u_t$, is the relative displacement of the impulsive mass; $x_t = u_t - u_b$ is the tower displacement (i.e. tower drift) and $x_b = u_b - u_g$, is the relative bearing displacement. ΔF is restoring force vector which is given as

$$\Delta F = \begin{Bmatrix} 0 \\ 0 \\ (1 - \alpha)F_y \Delta Z \end{Bmatrix} \quad (2.6)$$

Following the assumption of linear variation of acceleration over the time interval Δt . Stiffness k_b and damping C_b of isolation are defined as Δt incremental vectors $\{\Delta \ddot{x}\}$ and $\{\Delta \dot{x}\}$ are given by

$$\{\Delta \ddot{x}\} = a_0 \{\Delta x\} + a_1 \{\dot{x}\}^t + a_2 \{\ddot{x}\}^t \quad (2.7)$$

$$\{\Delta \dot{x}\} = b_0 \{\Delta x\} + b_1 \{\dot{x}\}^t + b_2 \{\ddot{x}\}^t \quad (2.8)$$

Where, $a_0 = \frac{6}{\Delta t^2}$; $a_1 = \frac{6}{\Delta t}$; $a_2 = -3$; $b_0 = \frac{3}{\Delta t}$; $b_1 = -3$; $b_2 = -\frac{\Delta t}{2}$ the subscript denotes the time. Substituting the values from equation (2.8) and (2.9) in the incremental form of equation of motion, the equation of motion can be written as.

$$\begin{aligned} [a_0 [m] + b_0 [c] + [k]] \{\Delta x\} \\ = ([m]\{r\}\ddot{u}_g - [m](a_1 \{\dot{x}\}^t + a_2 \{\ddot{x}\}^t) - [c](b_1 \{\dot{x}\}^t + b_2 \{\ddot{x}\}^t)) \\ - (\Delta F) \end{aligned} \quad (2.9)$$

After solving for incremental displacement vector from equation (2.9) the incremental velocity vector is obtained from the equation (2.8). The restoring force vector at time $t + \Delta t$ is obtained by

$$\{F\}^{t+\Delta t} = \{F\}^t + \{\Delta F\} \quad (3)$$

In order to estimate the force vector $\{\Delta F\}$ the incremental hysteretic displacement, Z is determined by solving first order differential equation (3.1)

$$\frac{q dZ}{dt} = -\beta |\dot{x}_b| Z |Z|^{n-1} - \tau \dot{x}_b |Z|^n + A \dot{x}_b \quad (3.1)$$

In order to estimate the force vector $\{\Delta F\}$ the incremental hysteretic displacement, ΔZ is determined by incremental solution techniques using equation (3.2) with the help of third order Runge-Kutta method. The force deformation behavior of the elastomeric bearing can be modeled by properly selecting the parameters Q_y , q , α , β , τ , n and A . The step-by-step computational procedure is as below.

- Assume an initial value of $\Delta Z = 0$ at first iteration value $j=1$.
- Substitute the value ΔZ in equation (2.6) and then putting the value of ΔF in equation (2.9) to obtain value of Δx .
- From equation (2.8) the velocity vector is determined at time step $t + \Delta t$
- Compute the revised value of ΔZ using the third order Runge Kutta method that is expressed as

$$\Delta Z = \frac{K_0 + 3K_2}{4} \quad (3.2)$$

Where, K_0, K_2 are Runge-Kutta constants.

$$k_0 = \Delta t f(\dot{x}_b^t, z) \quad (3.3)$$

$$k_1 = \Delta t f\left(\dot{x}_b^{t+\left(\frac{\Delta t}{3}\right)}, z + \frac{k_0}{3}\right) \quad (3.4)$$

$$k_2 = \Delta t f\left(\dot{x}_b^{t+\left(\frac{2\Delta t}{3}\right)}, z + \frac{2k_1}{3}\right) \quad (3.5)$$

Repeat Step (ii) & (iv) and iterate till following convergence criteria is satisfied.

$$\frac{\Delta Z_{j+1} - \Delta Z_j}{Z_m} \leq \textit{tolerance} \quad (3.6)$$

Where, subscript j denotes the iteration number; Z_m is the maximum value of hysteretic displacement of the bearing is expressed by.

$$Z_m = \sqrt{\frac{A}{\beta + \tau}} \quad (3.7)$$

$$k_b = \left(\frac{2\pi}{T_b}\right)^2 (M + m_{\text{Staging}} + m_b) \quad (3.8)$$

$$c_b = 2\xi_b \omega_b (M + m_{\text{Staging}} + m_b) \quad (3.9)$$

Where, T_b is the time period of isolation system =2sec and 4sec and ξ_b damping ratio of isolation system =0.1. After obtaining the acceleration vector, the base shear is computed, which is directly proportional to earthquake forces transmitted to the tank is expressed as,

$$f_b = m_c \ddot{v}_c + m_i \ddot{v}_i + (m_b) \ddot{v}_t \quad (\text{For non - isolated tank model}) \quad (4)$$

$$f_b = m_c \ddot{v}_c + m_i \ddot{v}_i + (m_b) \ddot{v}_t + 2(m_b) \ddot{v}_b \quad (\text{For isolated tank model}) \quad (4.1)$$

2.5. Verification of the Newark's step by step iteration procedure

To perform the verification of the proposed, the results of water free surface displacement obtained from the numerical model, is compared with experimental results. The test tank was selected for verification process has circular shape with dimension of 0.19×0.3 m in diameter and height, respectively. The water height in the tank is considered 0.125 m. The response of the circular tank was studied under the harmonic sinusoidal excitation. To prevent seismic damage of water tank natural frequency must be calculated, then the seismic frequency calculated via subjected to seismic wave should be difference of natural frequency. The test tank was excited with horizontal forced frequencies bigger than the first fundamental frequency of contained liquid which is obtained from the equation (4.2). The seismic wave motion is given by equation (4.3):



Figure 3.Experimental set-up-shake table test

For the circular and rectangular tanks, the first sloshing frequency is given by Eqn. (Housner, 1963):

For circular tanks

$$\omega_n = \frac{1}{2n} \sqrt{\frac{3.68g \tanh\left(3.68\frac{h}{D}\right)}{D}} \quad (4.2)$$

$$\chi(t) = D \sin \omega_t \quad (4.3)$$

In above formula D is maximum horizontal amplitude and ω is horizontal forced frequency which were considered to 0.0012 m and 6.221 HZ, n is number of oscillation modes. Natural frequency of first mode of experimental tank is equal to 2.19 HZ.

The Mann-Whitney analysis showed, there is no significant difference between the numerical and experimental data: (P-value =0. 319) > 0.01. Comparison between experimental and numerical results on verification processes are shown in Fig. 4.

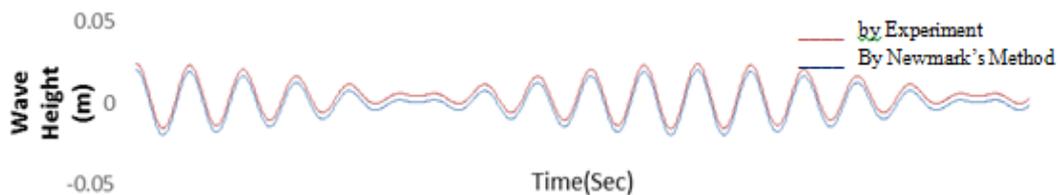


Figure. 4. Comparison between FEM results of sloshing wave height and experimental measurements

2.6. Earthquake Ground Motion

A Imperial Valley, 1940, El-Centro strong motion stations that recorded earthquake motions with peak ground accelerations larger than 0.21g selected for dynamic analysis; this records is shown in Figure. Due to the voluminous and time-consuming model analysis, the intensive volatility areas of the earthquake records is used for calculation.

Sr.No.	Record	Notation	Component	Direction	PGA	Magnitude
1	Imperial Valley, 1940, El-Centro	El-Centro	Normal (N)	X	0.26	6.95

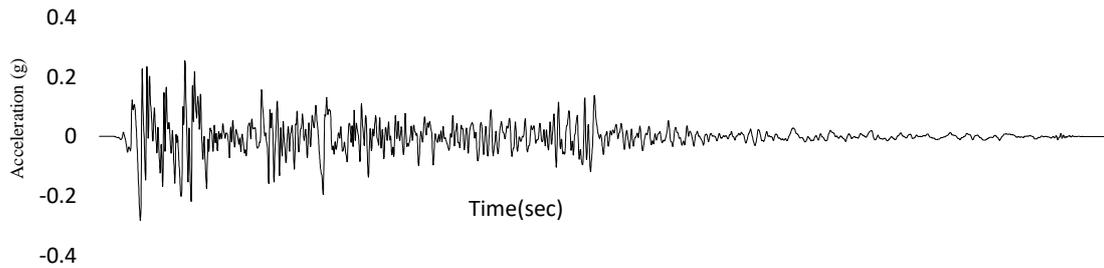


Figure 5 Imperial Valley, 1940, El-Centro strong motion stations that recorded earthquake.

2.7. Numerical Analysis of water tank (50 kL)

Sloshing characteristics of a tank contain natural frequencies and mode shapes that are important parameters in the analysis. The determination of these parameters can be very useful in describing the tank's behavior. Modal analysis is used to determine these characters and original mode of structure in horizontal and vertical directions. Convective and impulsive modes are the most important vibration modes that have the maximum of mass contribution effects. This analysis could be a starting point for other analyses such as time history analysis. The effect of non-classical damping on the response of base isolated tanks are investigated. For the present study the component S00E of Imperial Valley (1940) earthquake ground motion is used to investigate the response of the tank. A 50kl, tank with varying staging height 12m, 20m, 28m is analyzed.

The peak response of the tanks obtained by the exact and modal analysis are compared in Table 1 under El-Centro earthquake motion. The result shows, the peak response quantities such as base shear (f_s/w), displacement (x_c) and (x_b) are obtained by the modal analysis. Results indicate that the effect of non-classical damping are insignificant and the peak seismic response of isolated tanks can be accurately estimated by modal analysis.

Table 1 Peak Response of Base Isolated Shallow and Slender Tank

Earthquakes	Capacity of tank	Height of staging	Exact response Isolated (Lead-LRB)				Modal response Isolated (Lead-LRB)			
			x_c (cm)	x_t (cm)	x_b (cm)	f_s/W	x_c (cm)	x_t (cm)	x_b (cm)	f_s/W
El-Centro 1940 earthquake	50kl ($T_b=2$ Sec and $\xi_b=0.1$)	12m	42.66	0.59	9.23	0.041	42.93	0.50	9.19	0.039
		20m	35.27	0.45	9.29	0.032	35.88	0.33	9.29	0.034
		28m	55.7	0.44	6.48	0.029	54.7	0.35	6.46	0.03
	50kl ($T_b=4$ Sec and $\xi_b=0.1$)	12m	59.1	1.19	9.6	0.04	59.8	1.1	9.76	0.042
		20m	60.7	0.69	13.8	0.03	59.8	0.59	13.8	0.035
		28m	55.1	0.27	23.2	0.03	54.2	0.2	23.2	0.03

2.8. Time H Analysis of water tank (50 kL)

For complete investigation of seismic behavior of liquid storage tanks (50 kL), response quantities are base shear, displacement of the convective, impulsive and isolation system. The response of the isolation system is compared with the corresponding response of the tank without an isolation system. The response quantities of interest are base shear (measure at bottom of the foundation level), ($W=Mg$), sloshing displacement (x_c), impulsive displacement (x_i), isolator displacement (x_b). Table 2 and figure.6 shows the comparative study of the peak response of isolated elevated shallow against corresponding non-isolated tanks under Imperial

Valley (1940), The isolation parameters considered are $T_b=2\text{sec}$, 4sec & $\xi_b=0.1$ (Shallow Tank). The above results indicate that isolation reduces the base shear significantly, while sloshing displacement increases with increase in height of tank. The reduction in base shear is comparatively more in short staging height tanks, also there is reduction in base shear in 20m and 28m staging height tank. That's indicated, the reduction in base shear is slightly more in the tank with stiff framed structure, also the isolation techniques is also effective in 20m and 28m staging height tank. Table 2 indicates that tower drift is reduced due to isolation, significantly and this is more pronounced when tower structure is comparatively rigid. It is also observed that increased flexibility of tower structure transmits fewer earthquake forces, but it increases tower drift significantly. This implies that for stiff tower structures the reduction in the response achieved is more in comparisons to flexible tower structures. The peak sloshing displacement is increased significantly with an increase in height of staging in both the tanks.

Table 2 Peak Response of Elevated Tank (Shallow Tank)

Earthquake	Capacity of tank	Height of staging	Type of Tank	$T_b=2\text{sec}, \xi_b=0.1$				% Reduction Base shear
				Shallow tank				
				f_b/W	x_c (cm)	x_t (cm)	x_b (cm)	
Imperial Valley (1940)	50kl	12m	Non-isolated	0.17	30.47	2.89		
			Isolated (LRB)	0.042	43.84	0.6	8.56	75.08
			Isolated (Lead-LRB)	0.041	35.37	0.59	9.23	75.08
		20m	Non-isolated	0.098	35.63	2.95		
			Isolated (LRB)	0.035	59.42	0.48	9.21	63.84
			Isolated (Lead-LRB)	0.032	35.27	0.45	9.29	63.84
		28m	Non-isolated	0.085	35.86	2.92		
			Isolated (LRB)	0.03	60.43	0.79	6.48	63.56
			Isolated (Lead-LRB)	0.029	61.14	0.44	6.48	63.56

Earthquake	Capacity of tank	Height of staging	Type of Tank	$T_b=4\text{sec}, \xi_b=0.1$				% Reduction Base shear
				Shallow tank				
				f_b/W	x_c (cm)	x_t (cm)	x_b (cm)	
Imperial Valley (1940)	50kl	12m	Non-isolated	0.17	30.51	2.89		
			Isolated (LRB)	0.0425	60.73	1.19	9.62	75.00
			Isolated (Lead-LRB)	0.0425	59.16	1.19	9.62	75.00
		20m	Non-isolated	0.098	35.63	2.95		
			Isolated	0.0358	55.12	0.69	14.38	63.42
			Isolated (Lead-LRB)	0.0358	60.73	0.69	13.80	63.42
		28m	Non-isolated	0.085	35.83	2.95		
			Isolated	0.0309	55.12	0.27	22.88	63.57
			Isolated (Lead-LRB)	0.0309	55.12	0.27	23.28	63.57

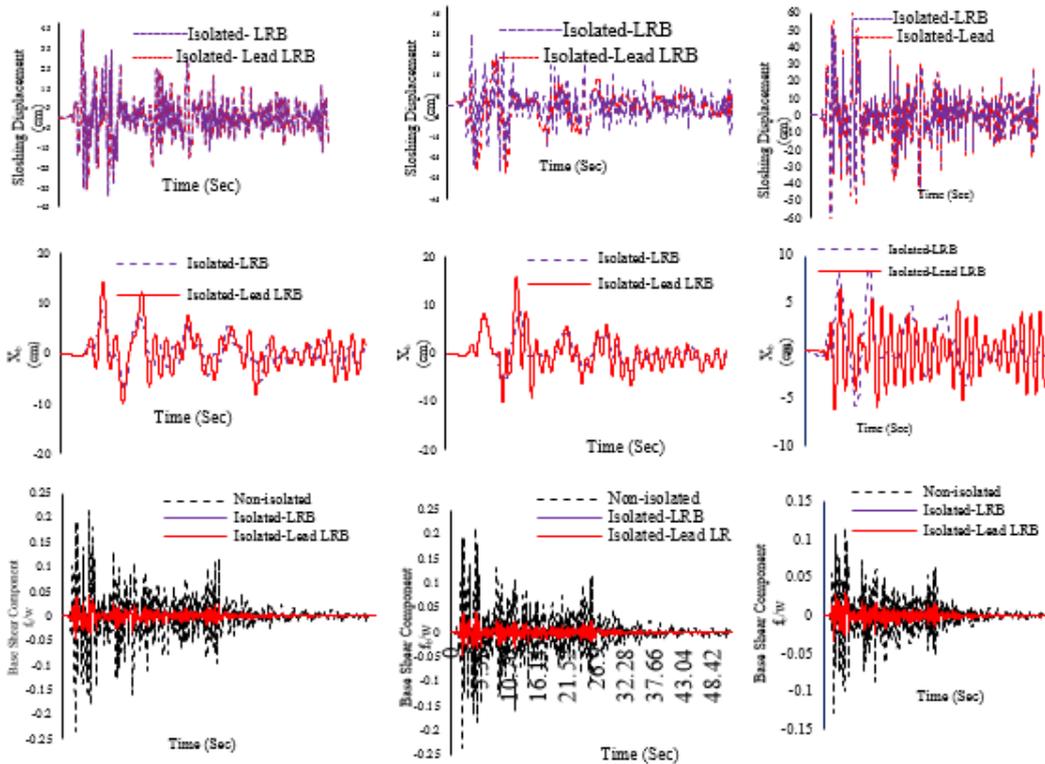


Figure.6 Time Variation Response Quantities of 50kl(12m,20m,28m) Staging Height Shallow Tank Due to Imperial Valley, 1940 Earthquake ($T_b = 2$ Sec, $\xi_b = 0.1$, $F_0 = 0.05$).

3. CONCLUSIONS

Some of the past and present research studies on seismic response analysis for liquid storage tanks were reviewed. In addition, Newark's step by step iteration procedure is used for solving the complicated equation of motion for fixed and bases isolated liquid storage tanks under X-direction horizontal components of real earthquake ground motions. The dynamic analysis to evaluate seismic response sloshing and base shear was proposed and validated by the experimental results. The conclusions obtained are summarized as follows:

- A verification of Newark's step by step iteration procedure was performed, the experimental and numerical values were compared with statistical analysis based on Mann-Whitney rules showed there is no significant difference between the numerical and experimental data:
- the influence of isolation damping on the seismic response of shallow tank (50 KL) with varying staging height which shows that the base shear, tower drift reduces for effective damping $\xi_b = 0.1$. Also, it has been found that reduction in base shear is significantly decreases while sloshing displacement gradually increases with increase in the height of tank.
- The influence of time period of isolation system on response of shallow tank investigated. It is observed that due to increase of isolation period base shear is reduced significantly because of increased flexibility of the isolation system transmit less acceleration to liquid container, hence less dynamic forces are generated. The sloshing displacement marginally increases with increase of time period and further increase in time period increase the sloshing displacement.

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